The Origin of the Heavy Element Content Trend in Giant Planets

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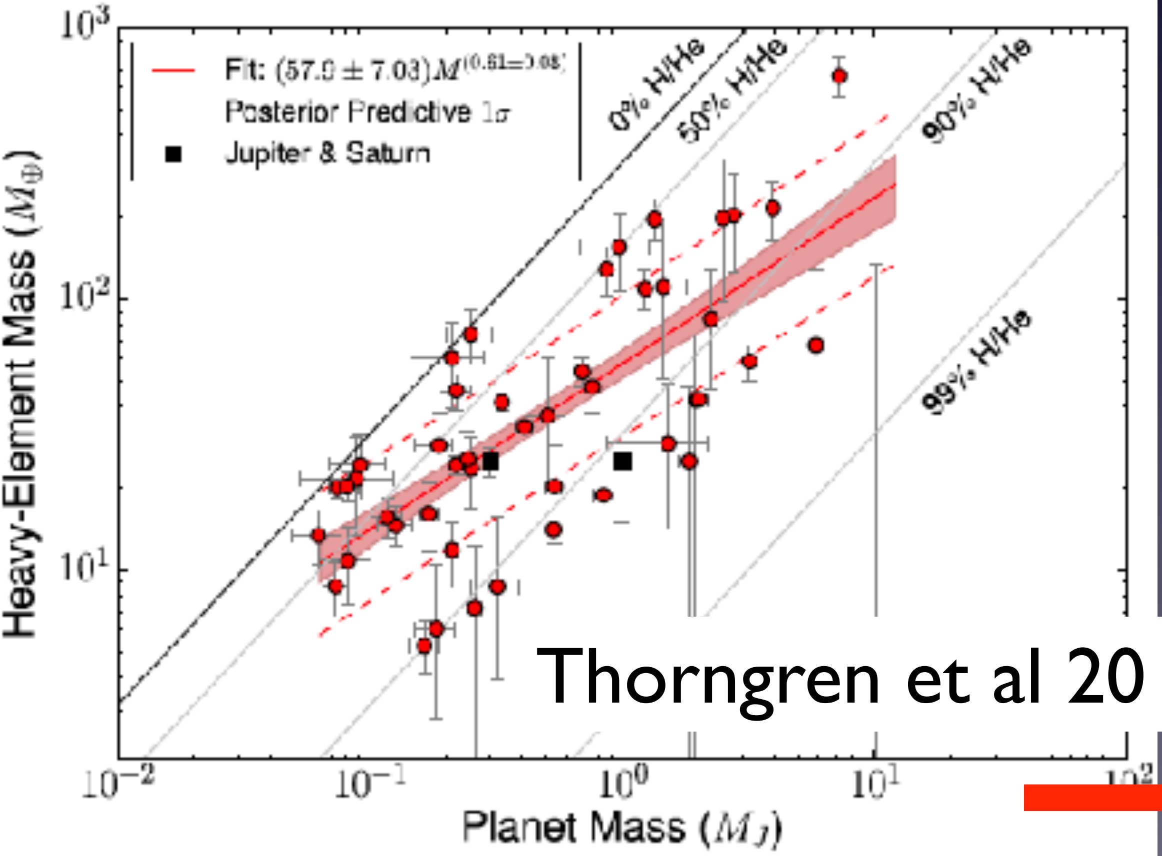
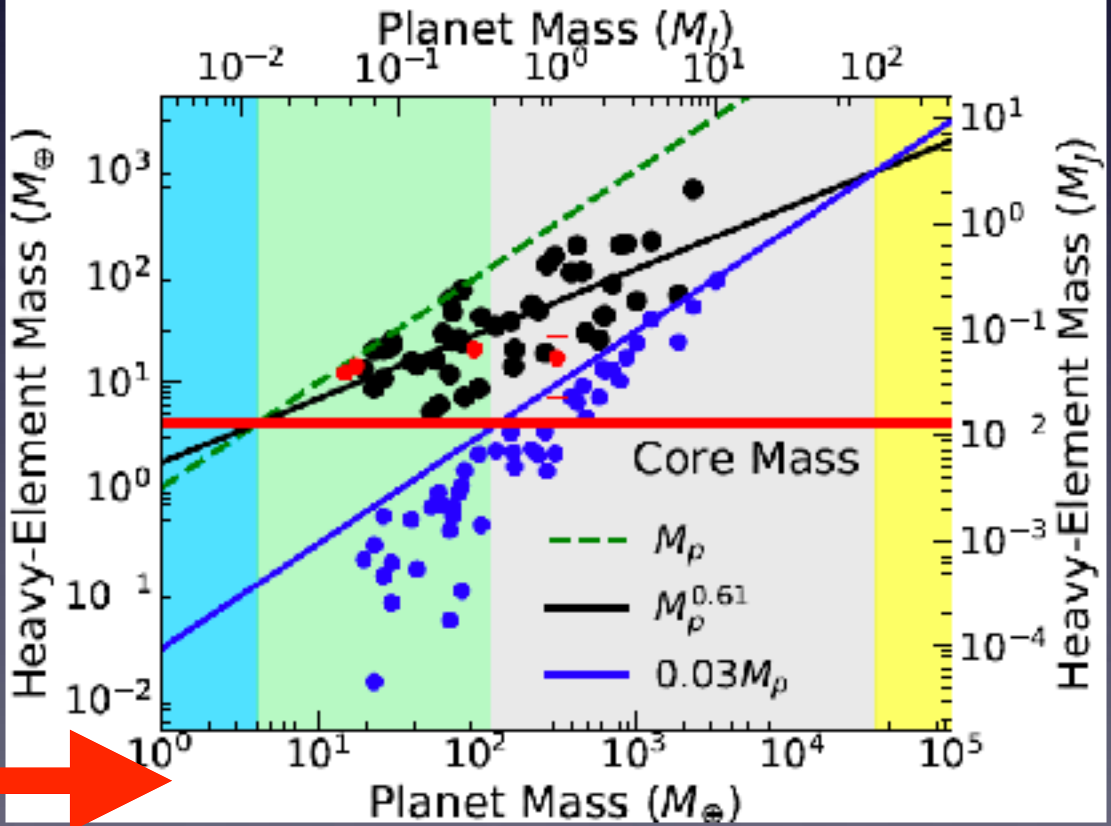


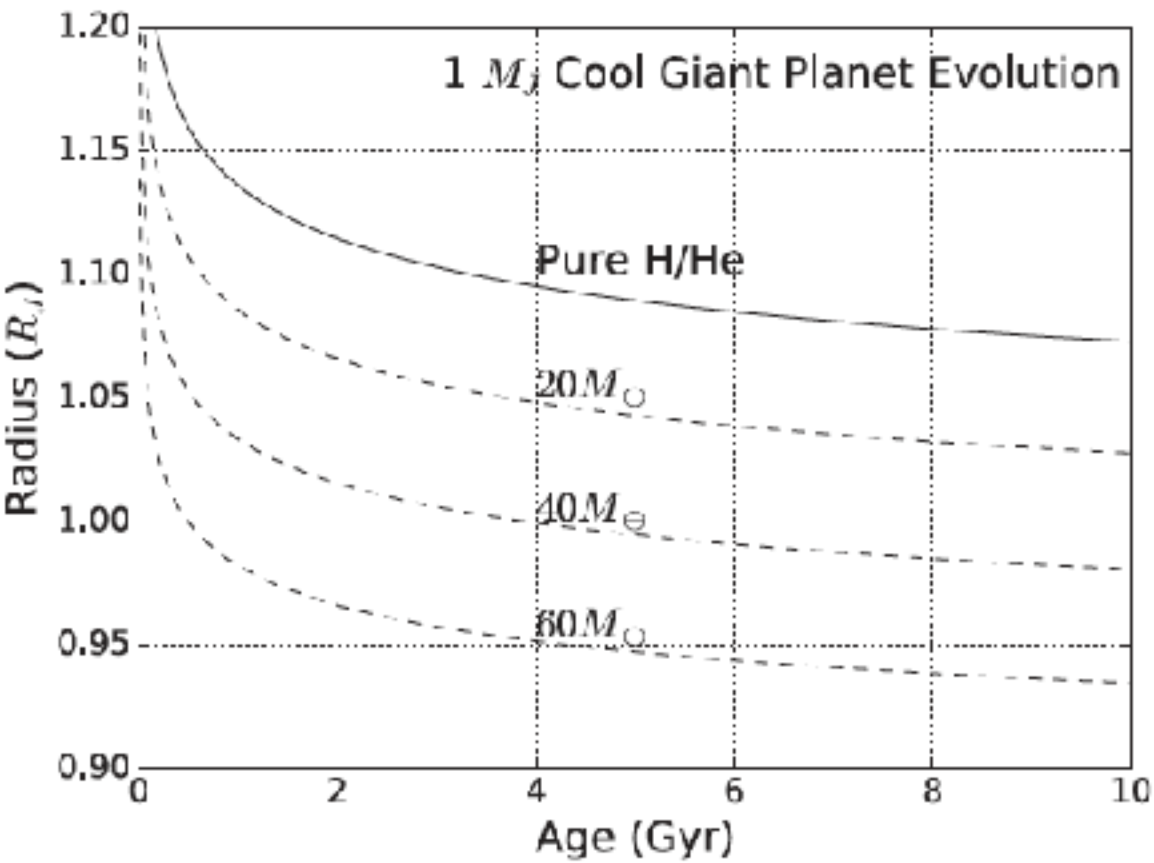
Thorngren et al 2016

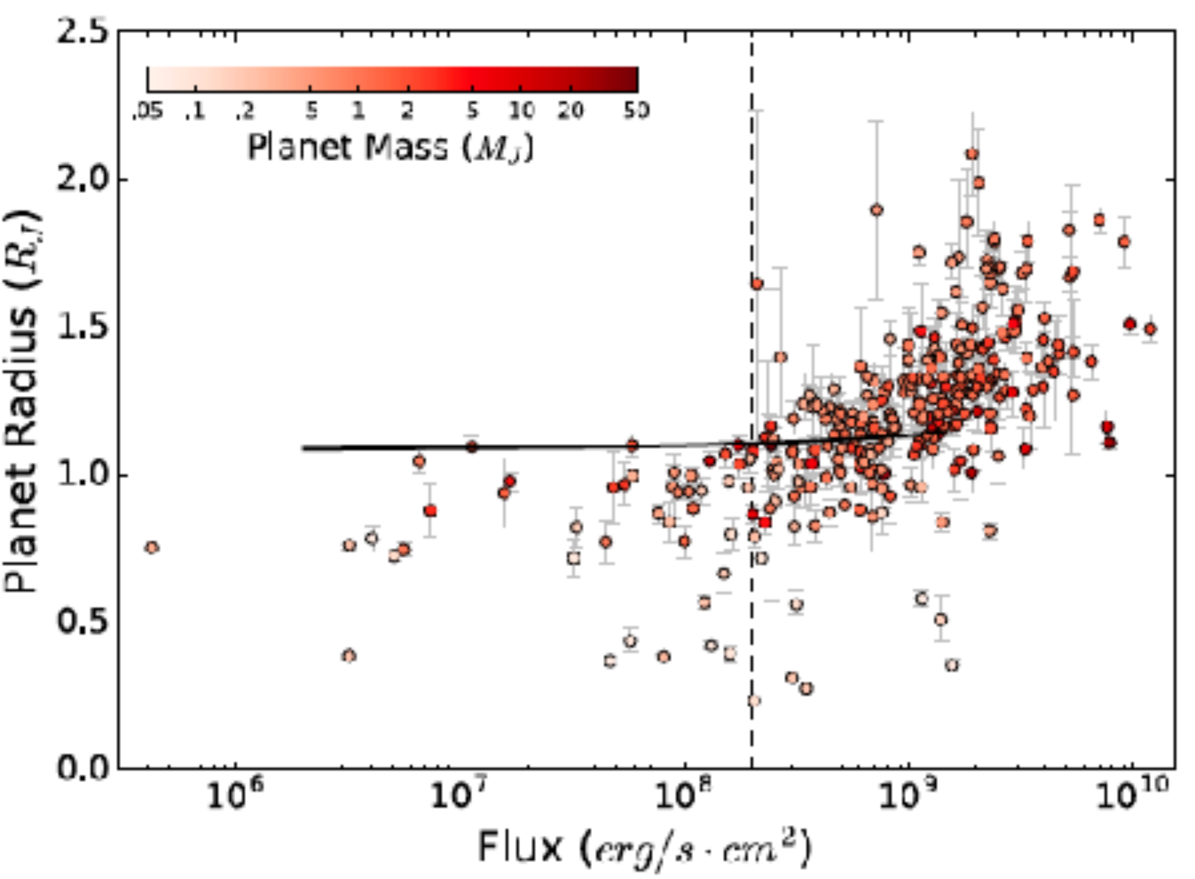


in collaboration with
Geoff Bryden (JPL/Caltech), Masahiro Ikoma (Tokyo Univ),
Gautam Vasisht (JPL/Caltech), Mark Swain (JPL/Caltech)

Estimate of the heavy element mass in observed exoplanets

e.g., Guillot et al 2006; Miller & Fortney 2011; Thorngren et al 2016

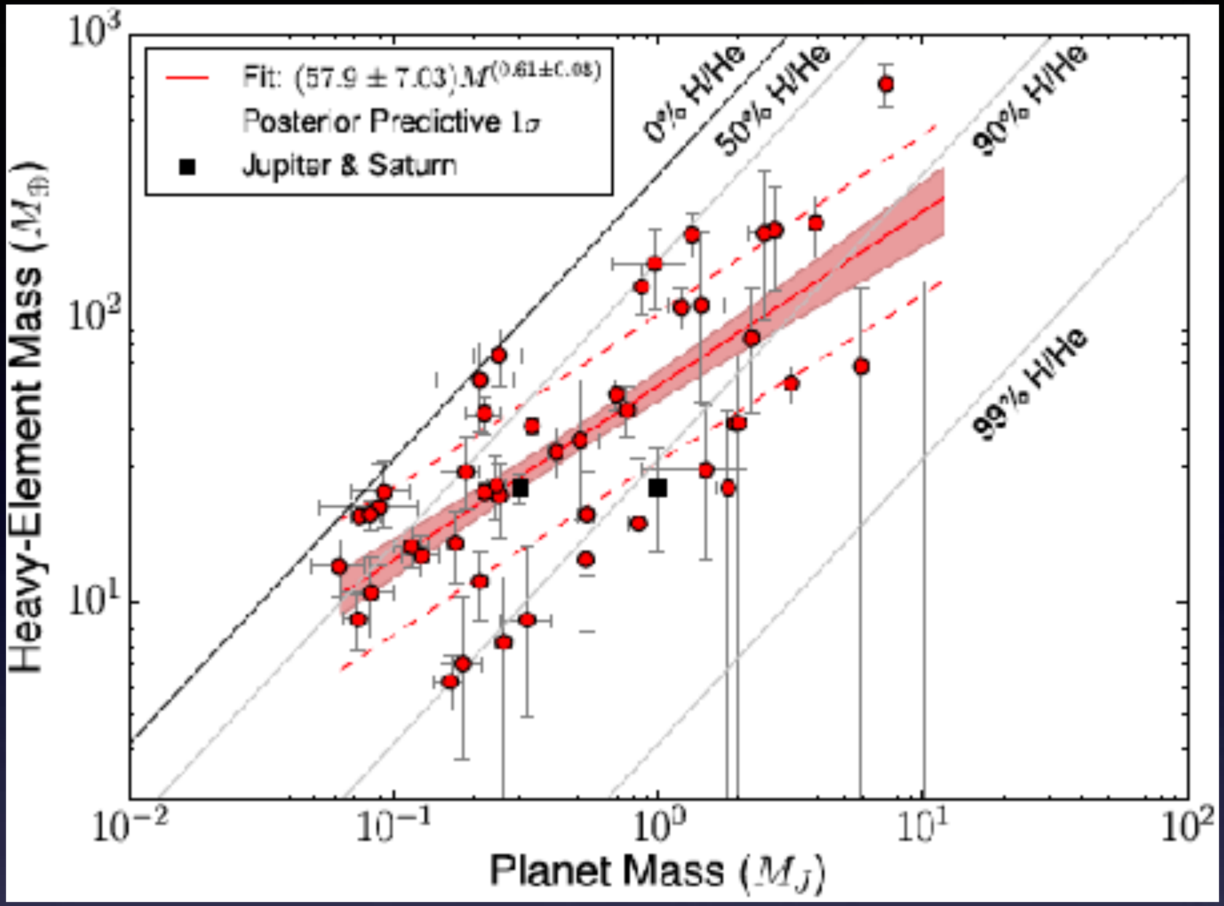


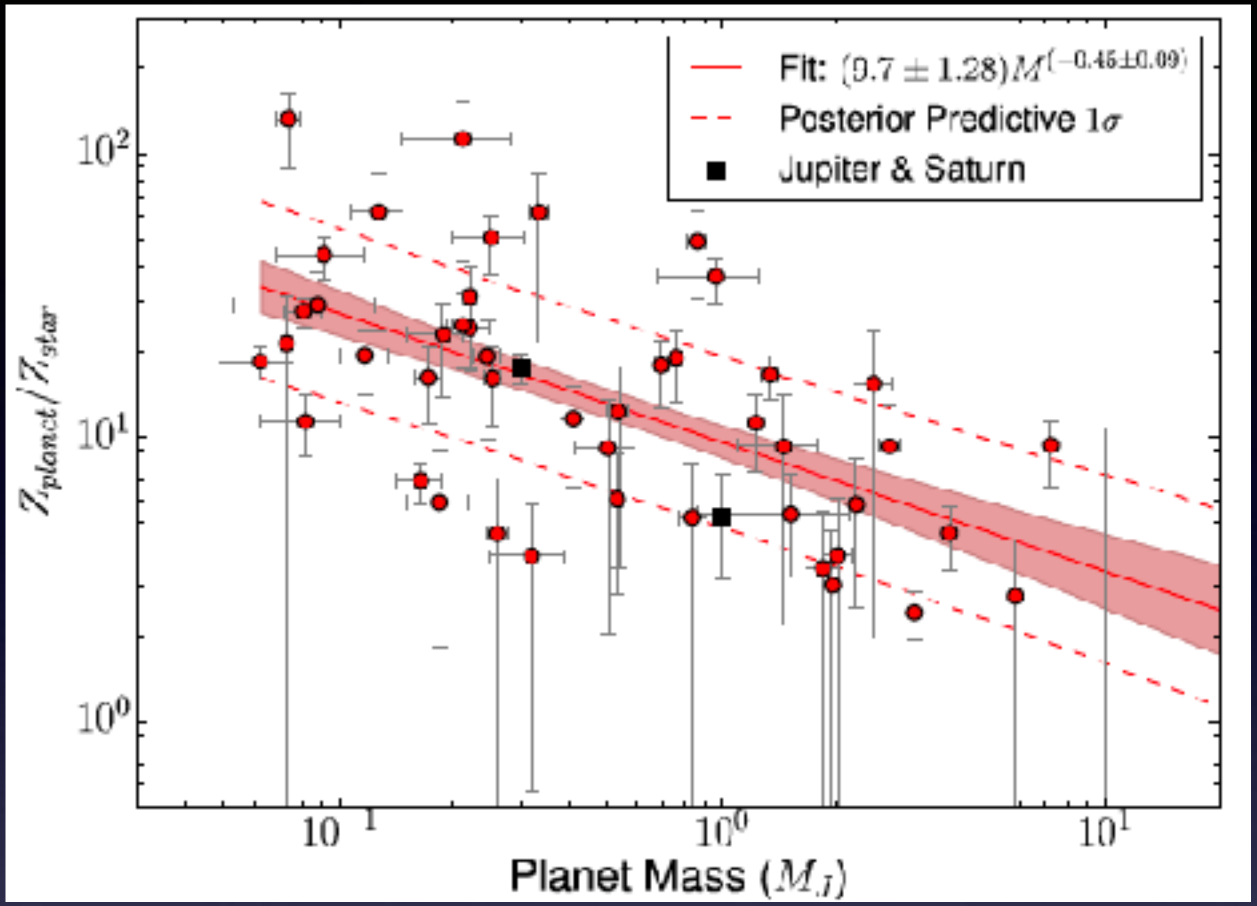


Distribute heavy elements in cores and envelopes, and compute the radius evolution of planets

Target selection: relatively cool close-in exoplanets

Results of Thorngren et al 2016 (T16)





$$M_Z \propto M_p^\Gamma \text{ with } \Gamma = 0.61 \pm 0.08 \simeq 3/5$$

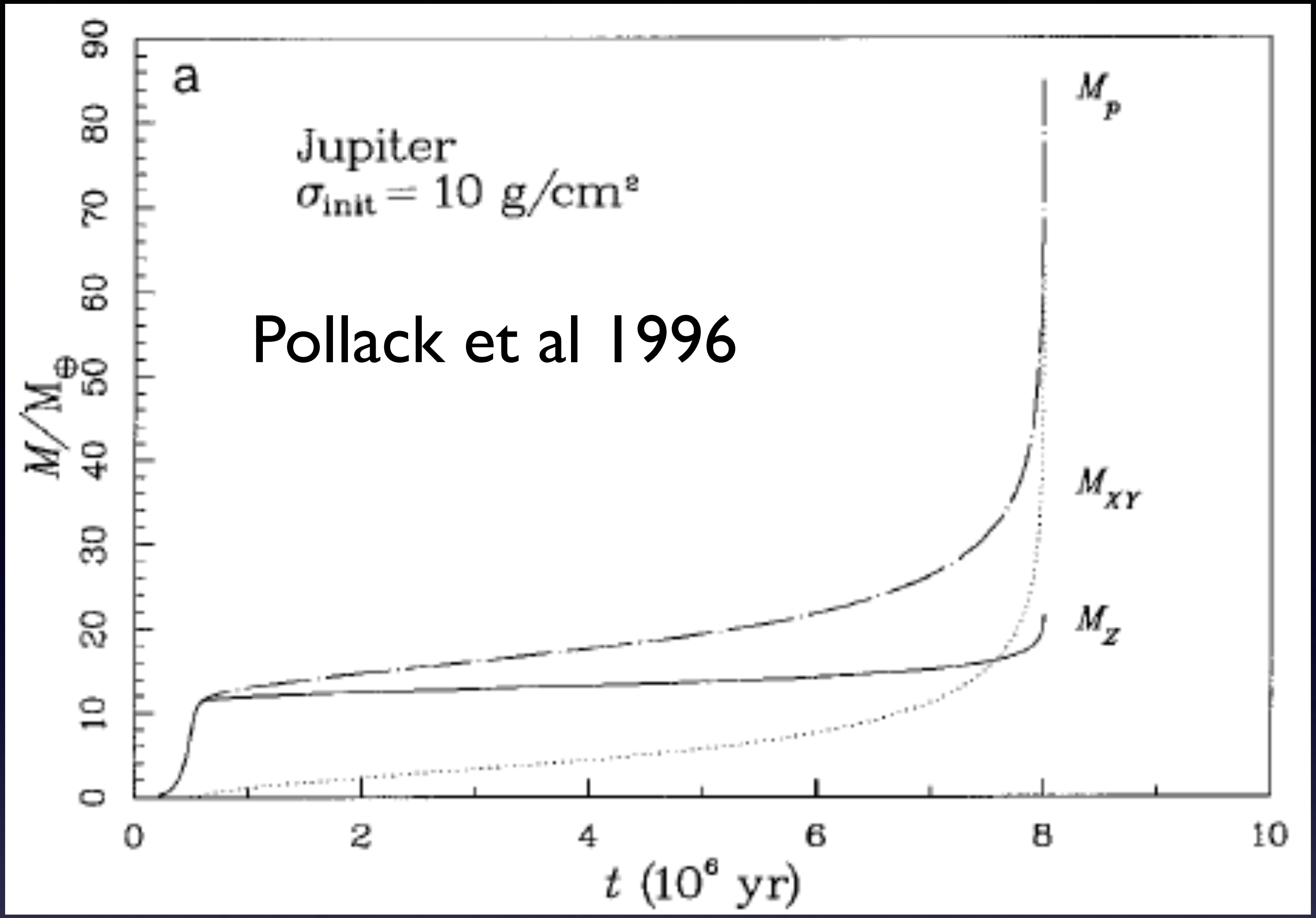
$$\frac{Z_p}{Z_s} = \frac{M_Z}{M_p Z_s} \propto M_p^\beta \text{ with } \beta = -0.45 \pm 0.09 \simeq -2/5$$

$\Gamma - 1 \simeq \beta$ => M_Z and M_p are almost independent of Z_s

M_Z : the total heavy element mass in planets with the mass of M_p

Z_s : the metallicity of the host star

Planet Formation via Core Accretion: Accretion of Gas and **Solids**



Pollack et al 1996

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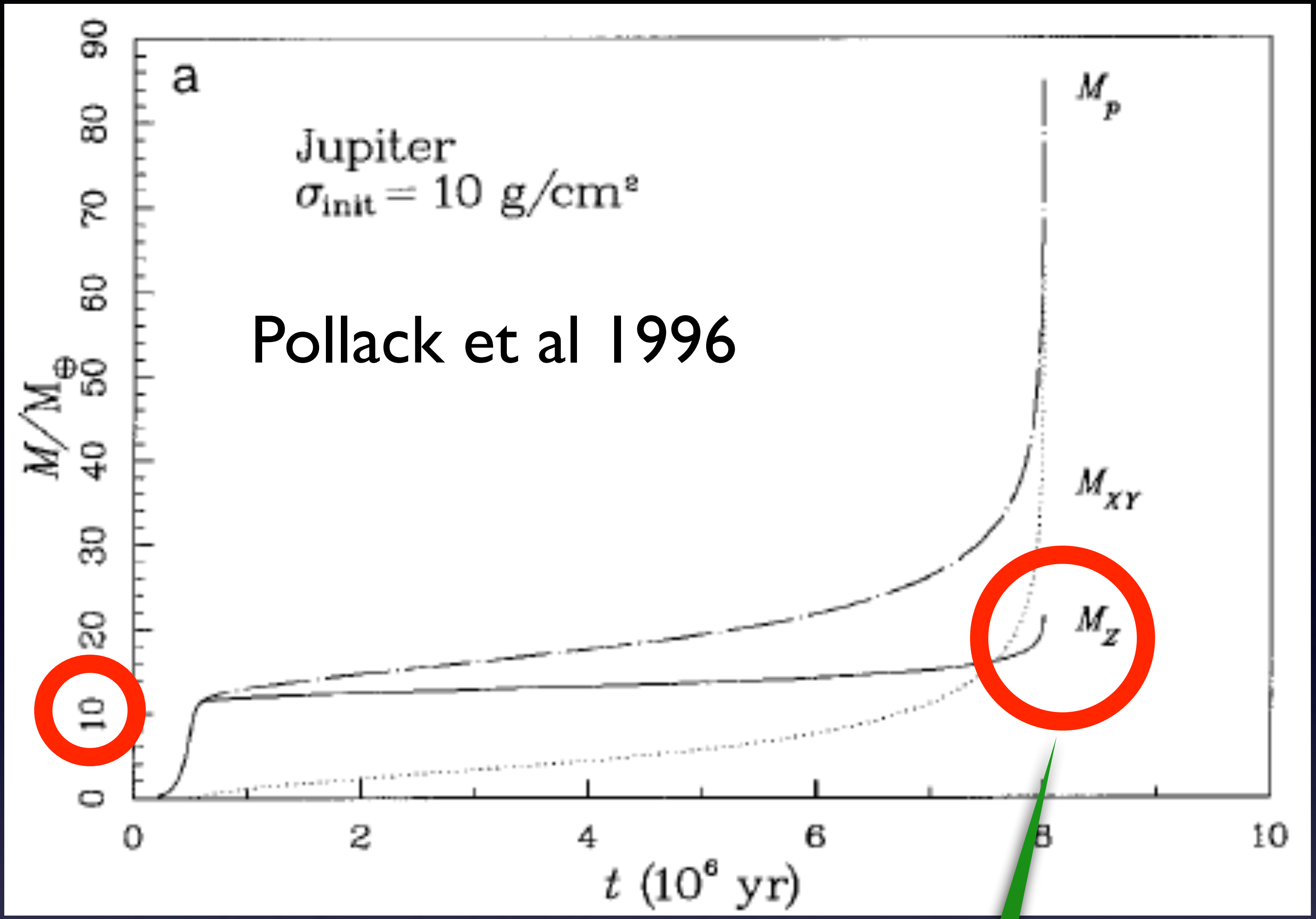


Pollack et al 1996

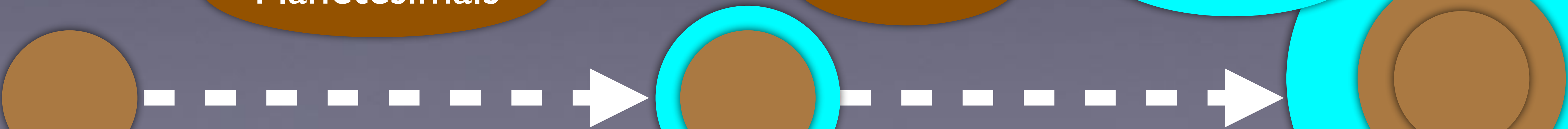
$$M_p = M_{XY} + M_Z$$

$$M_Z = M_{core} + M_{pl} + M_{pe} + M_{Z,gas}$$

Planetesimals

Pebbles

dust in gas



Power-law index	T16	M_{core}	M_{pl} (w/o Gap)	M_{pl} (w/ Gap)	M_{pe}
$\Gamma(M_Z \propto M_p^{\Gamma})$	3/5	0	1/3	3/5	1/3
$\beta(Z_p \propto M_p^{\beta})$	-2/5	-1	-2/3	-2/5	-2/3

Gas accretion is limited by disk evolution, following Tanigawa & Ikoma 2007

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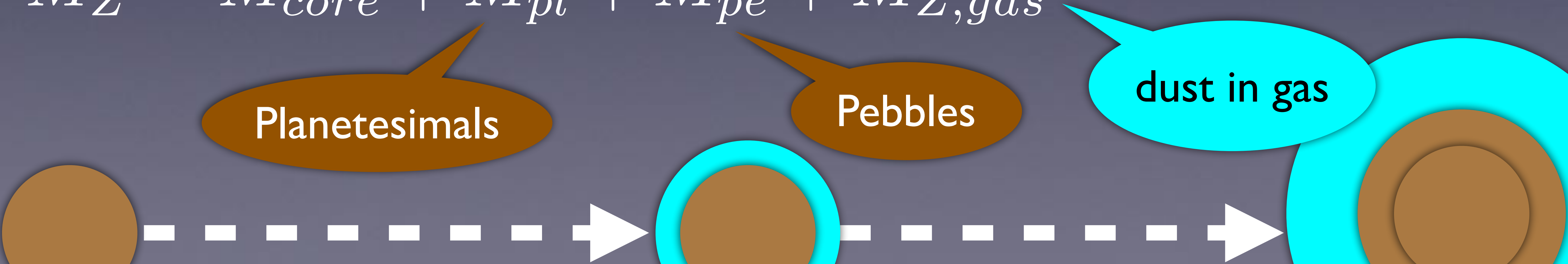

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Planets accreted solids from **gapped** planetesimal disks at the **final** formation stage

$$M_p = M_{XY} + M_Z$$

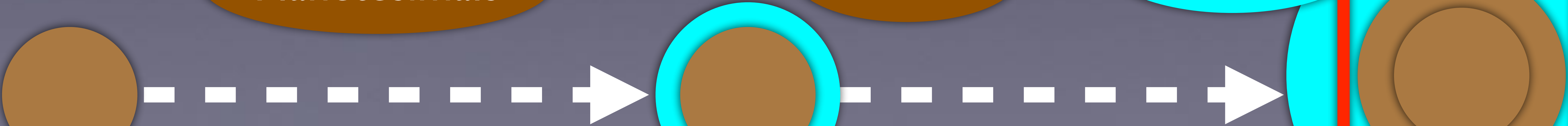
$$M_Z = \cancel{M_{core}} + M_{pl} + \cancel{M_{pe}} + \cancel{M_{Z,gas}}$$

This contribution is very minor

Planetesimals

Pebbles

dust in gas



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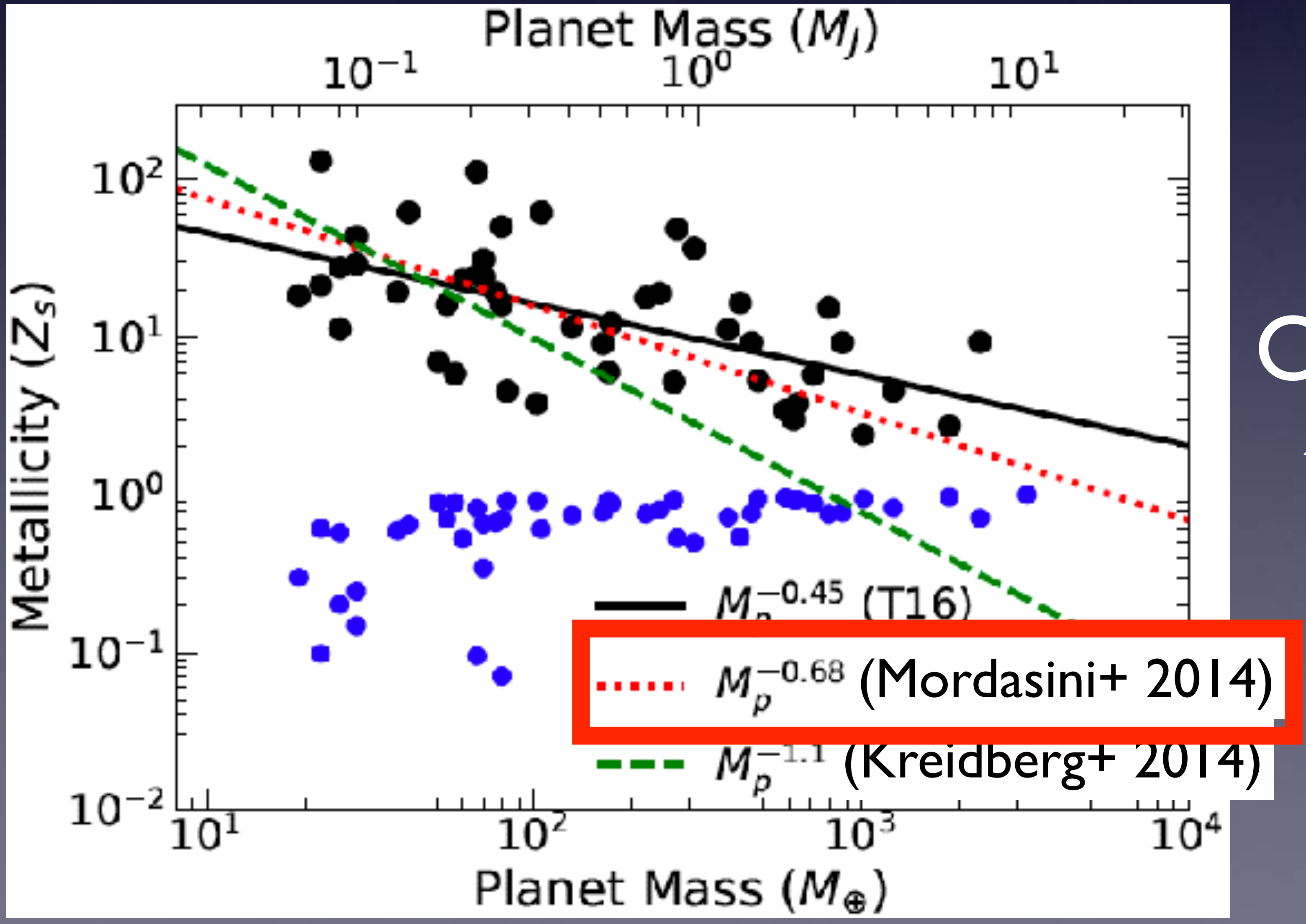

Comparison with previous studies

Our model can reproduce the results of Mordasini

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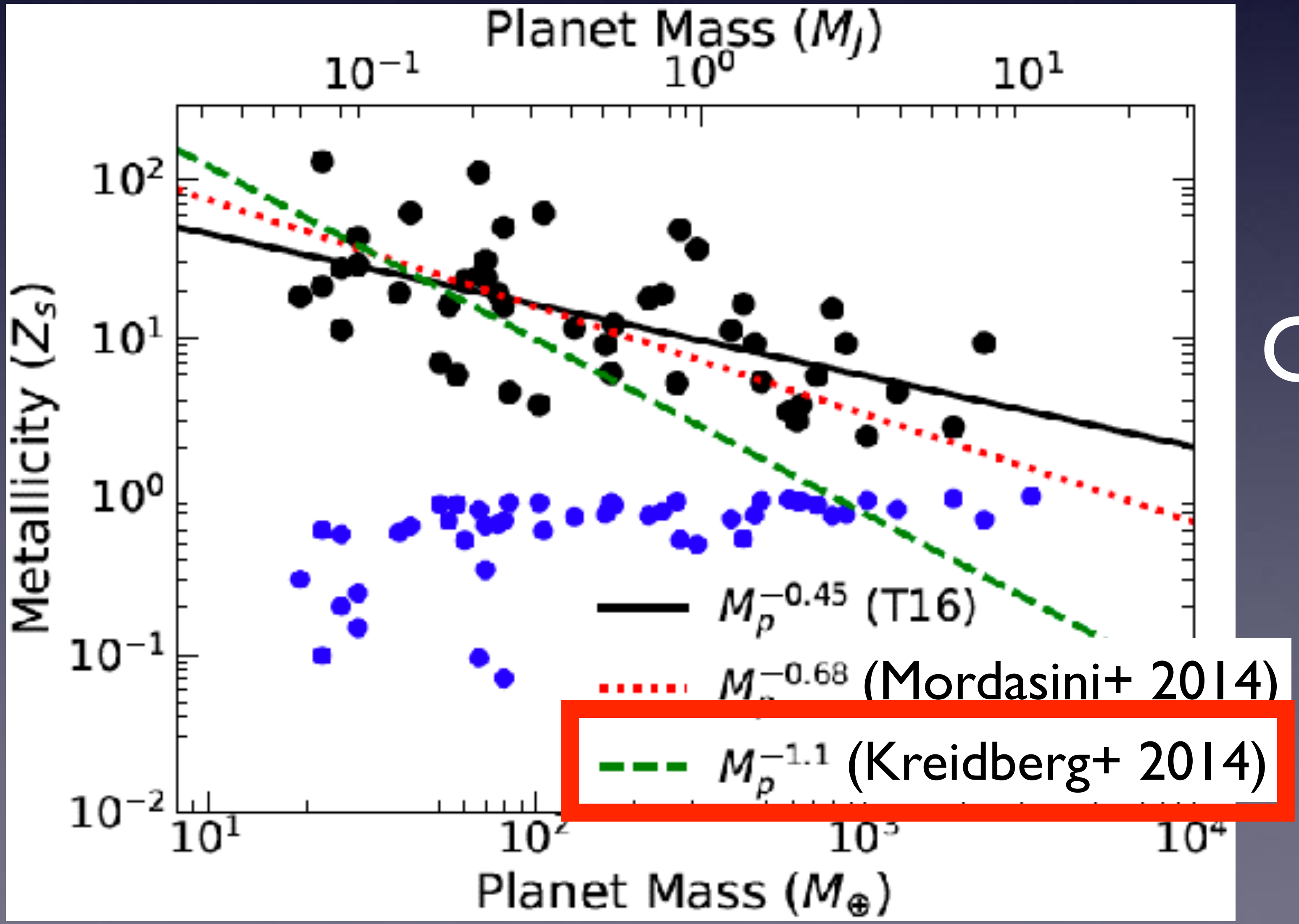

Comparison with previous studies

Our model can reproduce the results of Mordasini

Evolution of atmospheric metallicities in exoplanets can be explored

Summary

Hasegawa et al. 2018, ApJ in press (arXiv:1807.05305)

- Observed warm Jupiters tend to have correlations:

$$M_Z \propto M_p^{3/5} \qquad \frac{Z_p}{Z_s} = \frac{M_Z}{M_p}\frac{1}{Z_s} \propto M_p^{-2/5}$$

- We show that accretion of solids from **gapped planetesimal** disks can reproduce the above trends better
- Our results indicate that core formation, pebble accretion, and dust accretion accompanying gas accretion are **not** important
- Our analysis can **reproduce** the results of detailed population synthesis calculations (Mordasini et al 2014)
- Our results suggest that evolution of **atmospheric metallicities** can be explored in the $Z_p - M_p$ diagram